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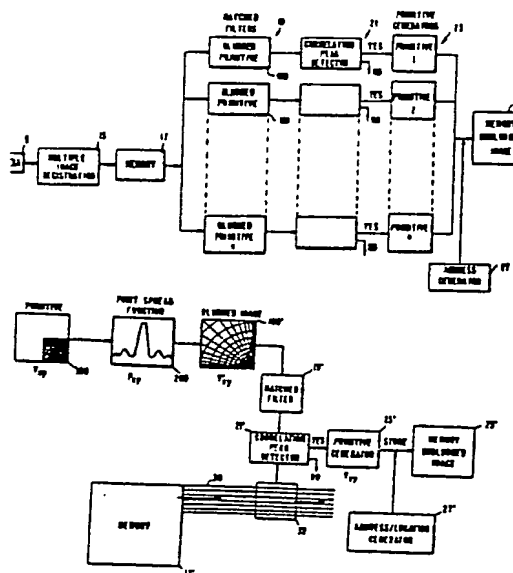
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(54) Title: RESOLUTION ENHANCEMENT AND ZOOM

(57) Abstract

The resolution is enhanced first by effectively decreasing the scan angle subtended between adjacent samples significantly below that of the Rayleigh limit to obtain an image blurred by the point spread function (or diffraction pattern) of the aperture. The next step is to process this blurred image at least to partially remove the blur. The unblurring process consists of correlating each small segment of the blurred image with blurred images of preconstructed image primitives and then synthesizing a new image comprising a mosaic of spatially correlated original (unblurred) primitives. The blurred images of the primitives are obtained from a complete set of image primitives comprising, ideally, all possible unblurred primitive shapes. These primitives are then blurred by convolution with the point spread function of the aperture of the imager.



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RESOLUTION ENHANCEMENT AND ZOOM

1 BACKGROUND OF THE INVENTION

Image systems including television cameras, charge coupled device imagers, forward looking infrared sensors, and infrared charge coupled device detectors
5 produce a video image having a resolution limited by the sampling rate of the imager. Designers of such systems typically limit the sampling rate to slightly more than two samples between the first zeros of the diffraction blur in accordance with the Nyquist
10 criteria. The Rayleigh resolution limit (computed from the size of the aperture and the wavelength of the scene energy) describes the limits of what the eye can see. A discussion of the Rayleigh limit is given in Jenkins and White, Fundamentals of Optics,
15 McGraw-Hill, 1957, at page 304. Specifically, a minimum angle of resolution between two points, for an imager having a circular aperture of diameter D sensing light wavelength λ , is $\frac{0.244\lambda}{D}$ radians. Accordingly,
20 scanning imager systems are typically designed so that the scan angle subtended between adjacent samples is less than $\frac{0.122\lambda}{D}$ radians.



1 SUMMARY OF THE INVENTION

 In this invention, the resolution of an object
is enhanced first by effectively decreasing the scan
angle subtended between adjacent samples to well below
5 that of the Rayleigh limit to obtain a better estimate
of an image blurred by the point spread function (or
diffraction pattern) of the aperture. The next step
is to process this blurred image at least to partially
remove the blur. The unblurring process consists of
10 correlating each small segment of the blurred image
with blurred images of preconstructed image primitives
and then synthesizing a new silhouette image comprising
a mosaic of spatially correlated members of the original
(unblurred) primitive set. The blurred images of the
15 primitives are obtained from a complete set of image
primitives comprising, ideally, all possible primitive
shapes. These primitives are blurred by convolution
with the point spread function of the aperture of the
imager.

20 In one embodiment of the invention, the increase
in sampling rate, beyond the Rayleigh limit in a conven-
tional imager having its sampling rate limited by the
Rayleigh criterion, is achieved by using multiple image
registration. This technique allows the present
25 invention to be used on existing imaging systems. In
the multiple image registration of this invention, a
single multiple-registered video frame, consisting of a
plurality of subpixels of reduced area, is constructed
from a plurality of normal video frames, each comprising
30 a plurality of standard pixels. The image motion or
camera jitter between subsequent normal video frames
determines the subpixel displacement in the multiple-
registered video frame. Implementation of multiple-
image registration in already existing system hardware

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1 may be accomplished using a correlation tracker, or
image motion compensating servo error or camera platform
stabilizing gyro error. The subpixel displacement is
determined in this way.

5 In another embodiment of the invention, the number
of samples in a given angle of scan in a conventional
imager may be increased by using image interpolation
and zoom. Image interpolation and zoom is useful when
there is not enough time to process a plurality of
10 video frames to construct a multiple-registered video
frame. Another technique is to use smaller sized
detectors in order to achieve dense sampling in a single
frame.

15 DESCRIPTION OF THE FIGURES

The invention may be understood by reference to
the accompanying drawings, of which:

FIG. 1a illustrates a typical aperture and sensor
receiving light from two point sources;

20 FIG. 1b illustrates the diffraction pattern or
point spread function corresponding to FIG. 1a;

FIG. 2a illustrates four multiple-registered
video frames;

25 FIG. 2b illustrates a sub-pixel mosaic synthesized
from the four multiple-registered video frames of FIG.
2a;

FIG. 2c illustrates an imaging device suitable
for generating multiple-registered video frames;

30 FIG. 3 illustrates a scheme for fast acquisition
of multiple-registered video frames;



1 FIG. 4 illustrates an image interpolation technique which may be used in this invention in lieu of the multiple-registration technique of FIGS. 2a, 2b and 2c;

5 FIG. 5 illustrates an exemplary set of image primitives;

 FIG. 6a illustrates the image primitive matched filter correlation technique for synthesizing an enhanced resolution image;

10 FIG. 6b illustrates the implementation of the technique of FIG. 6a for a single image primitive matched filter, as a simplified example; and

 FIG. 6c illustrates a point spread function of the same function shown in FIG. 6b.

15

DETAILED DESCRIPTION OF THE INVENTION

 FIG. 1a is a simplified schematic diagram illustrating two points A, B viewed through a circular aperture 1 (shown in cross-section) of diameter D. A lens 3 of a camera 5 senses the radiation of wavelength λ emitted or reflected from the two points A and B. The angle θ , subtended between the two points A and B at the lens 3, is equal to the Rayleigh limit $0.244\lambda/D$.

25 FIG. 1b is a diagram illustrating the corresponding diffraction patterns produced at the lens 3 by the radiation from point A (solid line) and from point B (dashed line) in which the ordinate corresponds the photon intensity and the abscissa corresponds the position along the X axis of FIG. 1a. Such diffraction patterns of point source images are uniquely characteristic of the aperture, and are termed "Point Spread Functions".

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1 The Rayleigh criterion establishes the resolution
limit of two points viewed through an aperture. Specifi-
cally, the Rayleigh criterion states that the minimum
perceptible separation between the two points A and B
5 occurs where the peak P(A) of the diffraction blur of
one point corresponds to the first zero Z(B) of the
diffraction blur of the other point. This is exactly
the condition illustrated in FIG. 1b. This criterion
is based upon the fact that, below this separation,
10 there is no longer a discernable diffraction valley
between the peaks. However, it is a principle of this
invention that the Rayleigh criterion relates to the
behavior of the human eye and is not a fundamental
limit on the resolution of an image viewed through a
15 particular aperture and, in fact, a greater resolution
is possible if processing is used. Specifically, the
shape of the blurred image of two points, whose
separation is precisely at the Rayleigh limit, is
different from that of a single point. Furthermore,
20 the blurred image of the two points continues to go
through subtle changes below the Rayleigh limit
until the two points actually coincide in the scene.
(Of course, upon coincidence they are definitely
unresolvable.) Accordingly, there is realizable
25 information contained in a blurred image of two
points separated by a distance below that of the
Rayleigh criterion. Extraction of this information
is accomplished in the present invention.

30 Multiple Image Registration

FIGS. 2a and 2b illustrate the multiple image
registration used in this invention with the simple
example of a video frame having only sixteen pixels,
four on each side. In FIG. 2a, a video frame "a",
35 bounded by the solid line whose corners are denoted



1 a₁₁, a₁₄, a₄₁ and a₄₄, comprises sixteen pixels each
centered around sixteen respective points symbolized
as a_{ij}. The location of each of the center points
a_{ij} of the sixteen pixels is illustrated in FIG. 2a
5 while the mosaic of the corresponding pixels themselves
is illustrated in FIG. 2b in solid line.

Multiple image registration is achieved by sampling
and storing the sixteen pixels of data comprising the
video frame a of FIG. 2a illustrated in solid line.
10 Then the camera 5 is displaced in the x direction so as
to sample a second video frame b illustrated in dashed
line comprising sixteen pixels b_{ij} and bounded by pixels
b₁₁, b₁₄, b₄₁ and b₄₄. The displacement in the x direc-
tion between the video frames a and b is equal to half
15 the distance between the center points a₁₁ and a₁₂. The
sixteen pixels of data corresponding to the sixteen
center points b_{ij} are sampled and stored. The camera
5 is again displaced to sample a third video frame c
bounded by pixels c₁₁, c₁₄, c₄₁ and c₄₄ in FIG. 2a. The
20 video frame c is displaced from the original video
frame a in the y direction by half the distance between
the center points a₁₁ and a₂₁. The sixteen pixels
corresponding to the sixteen center points c_{ij} are then
sampled and stored. The camera 5 is then displaced
25 from the location corresponding to the video frame c
in the x direction by a distance corresponding to half
the pixel spacing to sense a fourth video frame d
illustrated in FIG. 2a in dashed-dotted line whose
corner pixels bear indicea d₁₁, d₁₄, d₄₁ and d₄₄. The
30 sixteen pixels corresponding to the sixteen center
points d_{ij} of the video frame d are then sampled and
stored.



1 A composite of the stored data from the video
frames a, b, c and d is then formed by reorganizing the
data in the order illustrated in FIG. 2b. Specifically,
FIG. 2b illustrates the data corresponding to the pixel
5 center points a_{11} , b_{11} , c_{11} and d_{11} in a multiple-
registered or composite video frame indicated in dashed
line in FIG. 2b. Each of the points a_{11} , b_{11} , c_{11}
and d_{11} is now the center of a corresponding subpixel
illustrated in dashed line in FIG. 2b. The number of
10 subpixels in the resulting composite mosaic is equal
to the square of the sampling improvement multiplied by
the number of pixels in any one of the original video
frames (in our example $2^2 \times 16 = 64$ subpixels). The
dashed line subpixels of FIG. 2b are of smaller
15 dimension than the solid line pixels by a factor of 2.

As a general rule, in a multiple registration of
n video frames, the video frames are displaced from one
another by a fraction $(1/n)^{1/2}$ of the pixel spacing.
Thus, while FIG. 2b illustrates a multiple image regis-
20 tration of four video frames in which the pixel dimension
is reduced by a factor of two, other reduction factors
may be achieved by multiple image registration.

Even though the granularity of the video data has
been reduced by the multiple image registration, the
25 image represented by the data is nevertheless blurred
in accordance with the point spread function of the
aperture through which the image was viewed.

In practice, correlation of the spatial displace-
ment between video frames with the reorganization of
30 the stored video data may be made by means of a camera
or sensor 5 mounted on a controller 7 as indicated in
FIG. 2c. The controller may be a camera gyroscopic
stabilization platform whose gyro error may be auto-
matically sensed and used as the video frame displace-
35 ment. Alternatively, the platform 7 may be an image



1 motion compensator using gyro stabilization. Again,
the gyro error would define the displacement between
the subsequent video frames. Finally, a correlation
5 tracker may be used to track the actual displacement
due to camera jitter between video frames. Data from
the correlation tracker would define the displacement
between subsequent video frames. Each of these
techniques is compatible with existing systems.

Referring to FIG. 3, a video frame 10 is synthesized
10 by the multiple image registration of sixteen standard
video frames of about 500 lines each, could not be
entirely displayed on a standard video screen. Instead,
the screen could accommodate only a small fraction 10'
of the multiple-registered video image. Accordingly,
15 the data residing in those portions 10a, 10c, and 10d
of the video frame of FIG. 3 correspond to unnecessary
scan excursions by the imager 5 in the Y direction. It
is preferable in this invention to restrict the scan of
the imager 5 of FIG. 2c in the Y direction to cover
20 only the portion of 10 illustrated in FIG. 3 as 10',
10e, and 10b. In this way, data comprising the multiple-
registered image 10' which is actually displayed on a
television screen may be acquired about four times
faster than otherwise for a 4-fold multiple registration.

25 Referring again to FIG. 2b, it should be recognized
that each of the points a_{ij} , b_{ij} , c_{ij} , d_{ij} corresponds
to a word of video data which may be stored in the
memory of a computer. The word corresponding to each
of the points a_{ij} , b_{ij} , c_{ij} , d_{ij} may take on any number
30 in a range of values corresponding to an analog value
of the radiation intensity sensed at that point by the
camera 5. Alternatively, in a low performance system,
each word may simply be a binary value (black or white,



1 on or off). However, it is contemplated in this invention
that each word represents an analog value corresponding
to the intensity of radiation sensed by the imager at
the corresponding center point a_{ij} , b_{ij} , etc.

5

Image Interpolation and Zoom

It may not be possible to use multiple image
registration to generate subpixel video data. This may
occur, for example, when objects to be viewed in the
10 scene are moving so fast in comparison with the rate at
which subsequent video frames are generated, that there
is insufficient correlation of the fast moving objects
between subsequent video frames. In this special
situation, image interpolation and zoom may be used to
15 generate the subpixels, instead of multiple image
registration.

Referring to FIG. 4, a subpixel of video data is
generated from a single video frame. The exemplary
portion of the video frame a of FIG. 4 comprises a
20 plurality of stored words of video data in which only
the words corresponding to pixel center points a_{12} ,
 a_{21} and a_{32} represent a non-zero intensity, corresponding
to the shaded areas of the video frame a of FIG. 4.

Image interpolation is achieved by estimating the
25 value of a point located between pixels. The image
data is interpolated between the pixels to achieve a
linear transition between the three points a_{12} , a_{21}
and a_{32} , as illustrated in FIG. 4 in the heavier solid
line. The resulting interpolated image is represented
30 in cross hatching in FIG. 4. The new interpolated
image, corresponding to the crossed-hatched area, con-
tains more information than the old image corresponding
to the shaded or stippled area.

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1 Interpolation of the analog intensity values
among the subpixels in the shaded area is made in
accordance with the following equations defining the
intensity value of the data word representing a
5 subpixel a'_{ij} :

$a'_{ij} = a_{ij}$ if a_{ij} is the center point of
a sample pixel in the original video frame a .

Otherwise:

10 a'_{ij} = a linear interpolation between the
analog values of adjacent a_{ij} from the original video
frame a .

Data from sampled video frames can update the
estimates from previously interpolated subpixels if
combined by a suitable weighting factor. The foregoing
15 image interpolation and zoom techniques are well known
and are described in various publications including,
for example: Pratt, Digital Image Processing, Wiley &
Sons, New York, pages 110-116. Accordingly, the image
interpolation and zoom technique will not be described
20 in greater detail here.

In summary, by the use of either multiple image
registration or image interpolation and zoom, a video
image comprising a plurality of fine subpixels may be
constructed from a plurality of video frames comprising
25 a plurality of normally sized pixels. A larger number
of small detectors could also be used to improve
sampling density. However, the information contained
in the subpixel composite video frame is still blurred
in accordance with the diffraction point spread function
30 of the aperture through which the image was viewed.
Accordingly, there remains the task of removing the
blur, at least partially, from the image, and recon-
structing an unblurred image from the information
contained in the highly sampled video frame of
35 subpixels.



1 Unblurring by Matched Filters

 The composite image comprising a plurality of subpixels may be substantially unblurred by correlating each small segment of the composite blurred image with
5 a complete set of equally small blurred image primitives. An exemplary set of 25 image primitives is illustrated in FIG. 5. Whenever a peak correlation is detected between a particular image primitive and a particular
10 segment of the composite image, an equivalent unblurred image primitive is substituted in place of the blurred segment. In this manner, a synthesized reconstructed silhouette image is formed from a spatially correlated set of image primitives substituted in place of the
15 original blurred image segments to which they correspond.

 Before correlating the set of basic image primitives with the various segments of the blurred composite image, the image primitives themselves are first blurred by convolving them with the sensor
20 degradation consisting of both the point spread function of the aperture, through which the original scene was viewed, and the detector shape, which samples the diffraction limited image. Accordingly, both the blurred composite image and the image primitives to
25 which its segments are compared, are blurred by the same point spread function, thus enhancing correlation. This point spread function is a Bessel function defined by wavelength and the configuration of the aperture through which the scene is viewed, and may be computed
30 in a deterministic manner in accordance with well known principles of classical optics. Blurring of the image primitives, such as those illustrated in FIG. 5 with the sensor degradation, is performed in accordance with well known principles of convolution theory.

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1 The foregoing process is illustrated schematically
in FIG. 6a. The camera 5 generates video data which is
fed to a multiple image generator 15 which functions in
accordance with either the multiple image registration
5 previously described in connection with FIGS. 2a, 2b,
2c or the image interpolation described in connection
with FIG. 4. The generator 15 then feeds video data
corresponding to a composite image of subpixels into a
cumulative memory 17 which stores the combined video
10 frame of subpixels. Segments of the video frame data
stored in the memory 17 are then continuously fed
to a set of parallel matched filters 19. Each of the
matched filters 19 corresponds to a blurred version of
one primitive of a complete set of image primitives
15 such as those illustrated in FIG. 5. Correlation
between each segment of the video frame and each of the
matched filters is detected by a corresponding one of
the correlation peak detectors 21.

 If a particular one of the blurred primitives
20 matches a particular segment of the video data read
out from the memory 17, the corresponding one of the
peak detectors 21 will enable the corresponding one of
a plurality of primitive generators 23. The enabled
primitive generator feeds the corresponding original
25 (or unblurred) image primitive to a memory 25, the
selected image primitive being stored in a location
determined by an address generator 27. This location
corresponds to the location of the matching segment of
the original video frame stored in the memory 17. As a
30 result, feeding a continuum of blurred image segments
from the memory 17 through the matched filter 19
causes a new silhouette image to be synthesized in
the memory 25 comprising a plurality of matching
image primitives.

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1 It is contemplated that the correlation process
of FIG. 6a may be carried out using a memory and a
charge coupled device transversal filter system such
as that illustrated in FIG. 6b. In FIG. 6b, memory 17'
5 contains a plurality of pixels representing one frame
of video data corresponding to the composite blurred
image. The pixels are organized by row and column.
Matched filter correlation of the type illustrated in
FIG. 6a is implemented by the use of a charge coupled
10 device transversal filter comprising a plurality of
n-parallel charge coupled device serial registers 30.
In the example of FIG. 6b, $n = 6$.

The top six rows of the CCD memory 17' are
transferred serially from left to right out of the
15 memory 17', through the parallel CCD registers 30 and
beneath a planar array 32 of charge sensing gate
electrodes organized by n-rows and n-columns. This
defines the dimensions of each of the segments of the
video frame to be compared or matched as n pixels by n
20 pixels. The n-rows of sensing gate electrodes in the
array 32 are in vertical registration with the n-rows
of the stored image 30. The spacing in the x direction
in the gate electrodes in the array 32 corresponds to
the serial spacing of charge packets in each of the
25 image registers 30.

As the top six rows of data from the memory 17'
are clocked from left to right through the CCD
registers 30, successive segments of the video data
comprising six rows and six columns are read out.
30 Specifically, the magnitude of each charge packet in
each six-by-six segment of data passing beneath the
array 32 is sensed by sensing the electrical potential
of each individual sensing gate electrode in the
array 32. Each time data is clocked sequentially from
35 left to right by one pixel through the register 32, a



1 new segment of video data is read out from the array 32
and fed to a corresponding one of 21' of the correlation
peak detectors 21. This occurs once each CCD clock
cycle. The process continues, pixel by pixel, until
5 the entire image has been processed. Operation of
charge coupled device transversal filters of this sort
is well known in the art and will not be described
further. Charge coupled device image processing with
transversal filters and CCD sense electrode arrays is
10 described, for example, in: Nudd et al, "A CCD Image
Processor for Smart Sensor Applications", Proceedings
of the Society of Photo-Optical Instrumentation
Engineers, San Diego, California, 1978, Vol. 155,
pages 15-22.

15

Convolution and Correlation

A simplified description of the convolution and
correlation processes for a particular one of the image
primitives of FIG. 6a will now be given with reference
20 to FIG. 6b. Each image primitive of FIG. 5 is quantized
into an array of n columns and n rows of data words,
 V_{ij} . A graphic representation of the array corresponding
to the image primitive 100 of FIG. 5 is illustrated in
FIG. 6b. An exemplary aperture point spread function
25 P_{xy} is illustrated in FIG. 6c. It may be digitized
into an array of m rows and m columns of data words
corresponding to the number of rows and columns of
subpixels in a complete multiple-registered frame.
The result is a matrix P_{ij} of m columns and m rows of
30 data words, comprising the point spread function matrix
200 indicated in FIG. 6b. The following is a partial
representation of an exemplary point spread function
matrix:

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[illegible]

15 In order to generate a blurred "version" of each image primitive, such as the primitive 100 in FIG. 6b, the primitive 100 is convolved with the point spread function matrix 200, yielding the blurred primitive 100', as indicated in FIG. 6b. Each data word V'_{ij} in the i^{th} row and the j^{th} column of the blurred primitive 100' is
20 computed from the point spread function data words P_{ij} and the unblurred primitive data words V_{ij} as follows:

$$V'_{ij} = \sum_k \sum_l P_{k-i, l-j} V_{kl}.$$

The blurred primitive 100' is then used as an array or matched filter 19' of $n \times n$ subpixels of data words. The plurality of matched filters 19 comprises, for example, each of the image primitives of FIG. 5 convolved with the point spread function 200, in accordance with FIG. 6b.



1 The $n \times n$ matched filter 19' is correlated with
each $n \times n$ image segment sensed by the array 32, the
correlation surface is operated on by the two-dimensional
correlation peak detector 21'. If the detector 21'
5 senses a peak correlation, the primitive generator 23'
is enabled by the detector 21' to generate a block of
 n -rows and n -columns of data words corresponding to the
unblurred image primitive 100. The data from the
generator 23' is stored in the memory 25' in an address
10 specified by the address generator 27'. The address
generator 27' directs the image primitive block of
data in the memory 25' to the location corresponding
to the original location of the correlated data segment
of the blurred video frame stored in the memory 17'.

15 Computation of the correlation by the detector 21'
is performed in accordance with well-known correlation
techniques in signal processing theory and, therefore,
will not be described herein in detail.

 The synthesized image stored in the memory 25
20 comprises a mosaic of selected image primitives and
has a better resolution than any one of the video
frames originally generated by the camera 5. It is
contemplated that the performance may be enhanced by
the use of a more complete set of image primitives than
25 that illustrated in FIG. 5.



CLAIMSWhat is Claimed is:

- 1 1. In an imaging system comprising an imager
which may view a scene through an aperture characterized
by a point spread function and means responding to said
imager for generating successive frames of video data
5 words characterized by a first sampling rate, a system
for enhancing image resolution, comprising:
- means for converting said video data words
into a synthesized video frame of video data words,
said synthesized video frame characterized by a second
10 higher sampling rate;
- a plurality of image primitives, each of said
image primitives comprising a matrix of video data
words;
- means for convolving each of said image
15 primitives with said point spread function to generate
a set of blurred image primitives;
- means for computing the correlation between
each of said blurred image primitives and each
small segment of said synthesized video frame and
20 detecting a peak correlation therefrom;
- a memory for storing a mosaic of selected
image primitives; and
- means, responsive whenever said correlation
means detects a two-dimensional peak correlation between
25 a particular one of said blurred image primitives and
one of said segments of said synthesized video frame,
for writing a particular one of the unblurred ones of
said image primitives into said image primitive mosaic
storage memory at a location corresponding to the
30 original location of said particular synthesized video
frame segment in said synthesized video frame.



1 2. The system of Claim 1 wherein said means for
converting into a synthesized video frame comprises
multiple image registration means for forming a mosaic
of displaced ones of said subsequent video frames
5 generated by said imager.

1 3. The system of Claim 1 wherein said means for
converting into a synthesized video frame comprises means
for performing image interpolation in a single one of
said subsequent video frames.

1 4. The system of Claim 1 further comprising an
array of detectors having a detector-to-detector sampling
rate greater than the Nyquist rate.

1 5. The image system of Claim 1 wherein each said
small segment comprises n rows and n columns of said
data words and said means for generating a synthesized
video frame comprises a memory device for storing
5 said synthesized video frame data words, and wherein
said correlation means comprises a charge coupled
device transversal filter including n -parallel
registers receiving data from said charge coupled
device memory, said correlation means comprising the
10 equivalent of a planar array of n rows and n columns
of sense electrodes overlying said parallel registers,
said electrode array further comprising means for
detecting each segment of video data words transferred
through said parallel registers, and transmitting
15 said detected video data words to a correlation
computator, wherein said correlation computator
computes a correlation between said detected segment
of video data words and said digitized version of a
corresponding one of said blurred image primitives.



1 6. In an imaging system, a method for employing
a set of primitives to enhance an image whose resolution
is degraded by system limitations including blurring
caused by focus, diffraction and sampling, said method
5 comprising:

generating a set of degraded primitives by
degrading said primitives in the same manner as the
image is degraded by said system limitations;

10 correlating the intensity distribution of a
sampled segment of said degraded image with the intensity
distributions of said degraded primitives and selecting
the most correlated degraded primitive;

synthesizing an enhanced image by displaying
the undegraded version of said selected degraded
15 primitive at the image location where the best match
occurs between said sampled degraded image segment and
said selected degraded primitive.

1 7. The method of Claim 6 further comprising the
additional step of:

increasing the sampling density of the degraded
image and the degraded primitives prior to comparing
5 the intensity distributions of degraded primitives and
sampled segments of said degraded image.

1 8. The method of Claim 6 wherein said degraded
primitives are generated by viewing said primitives
through said imaging system so that the degrading
effects of said system limitations are imparted to said
5 primitives at the output of said system.



- 1 9. The method of Claim 6 wherein the correlation of intensity distributions is made between sampled degraded image segments and degraded primitives of similar size to each other.
- 1 10. The method of Claim 6 wherein said degraded primitives are generated mathematically by convolving said primitives with a function representing said system limitations.
- 1 11. The method of Claim 6 wherein said sampled segments of said degraded image have overlapping portions.



Fig. 1a.

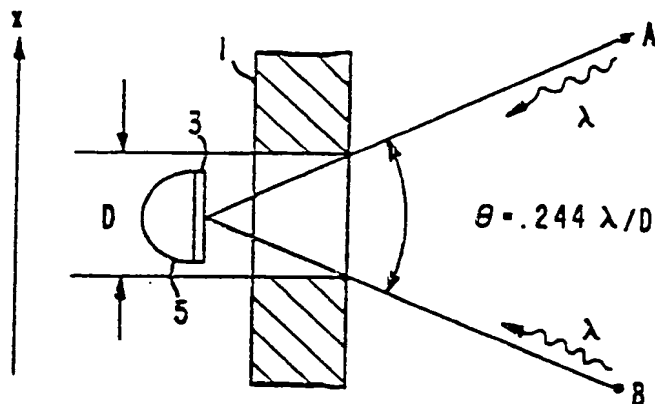


Fig. 1b.

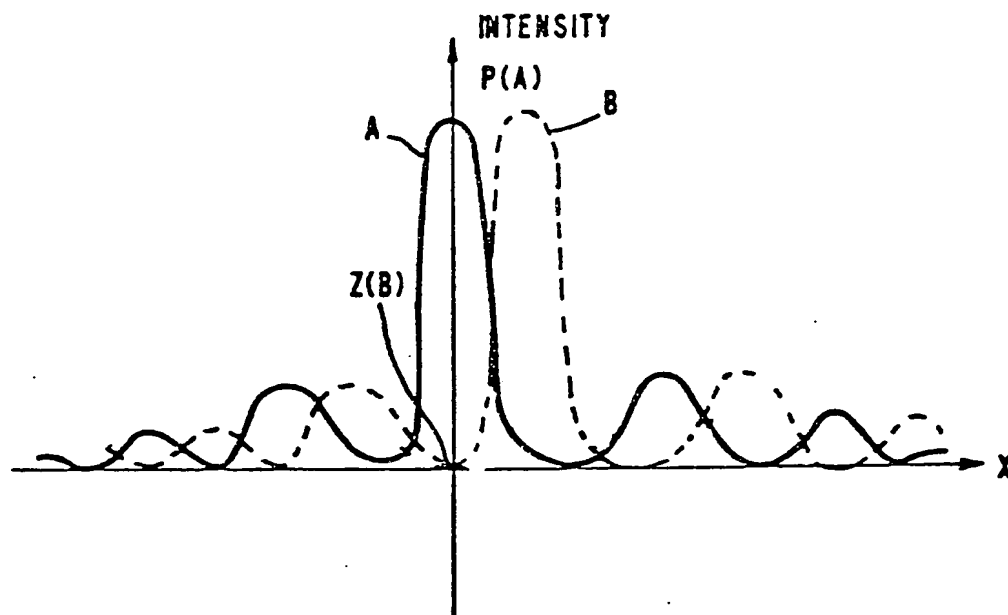


Fig. 2a.

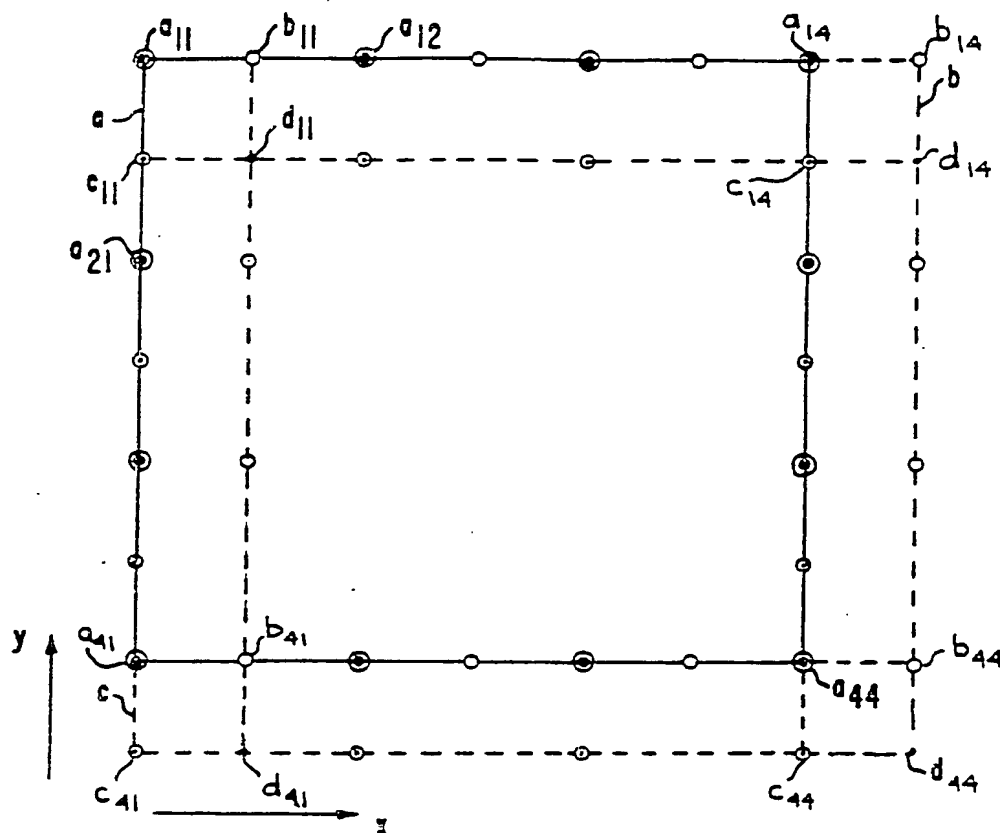
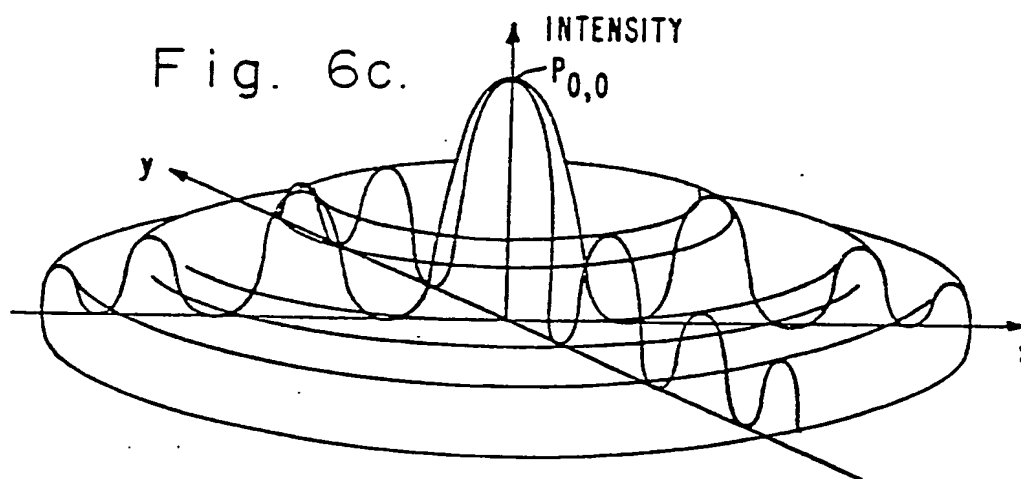


Fig. 6c.



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Fig. 2b.

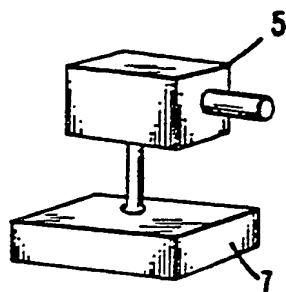
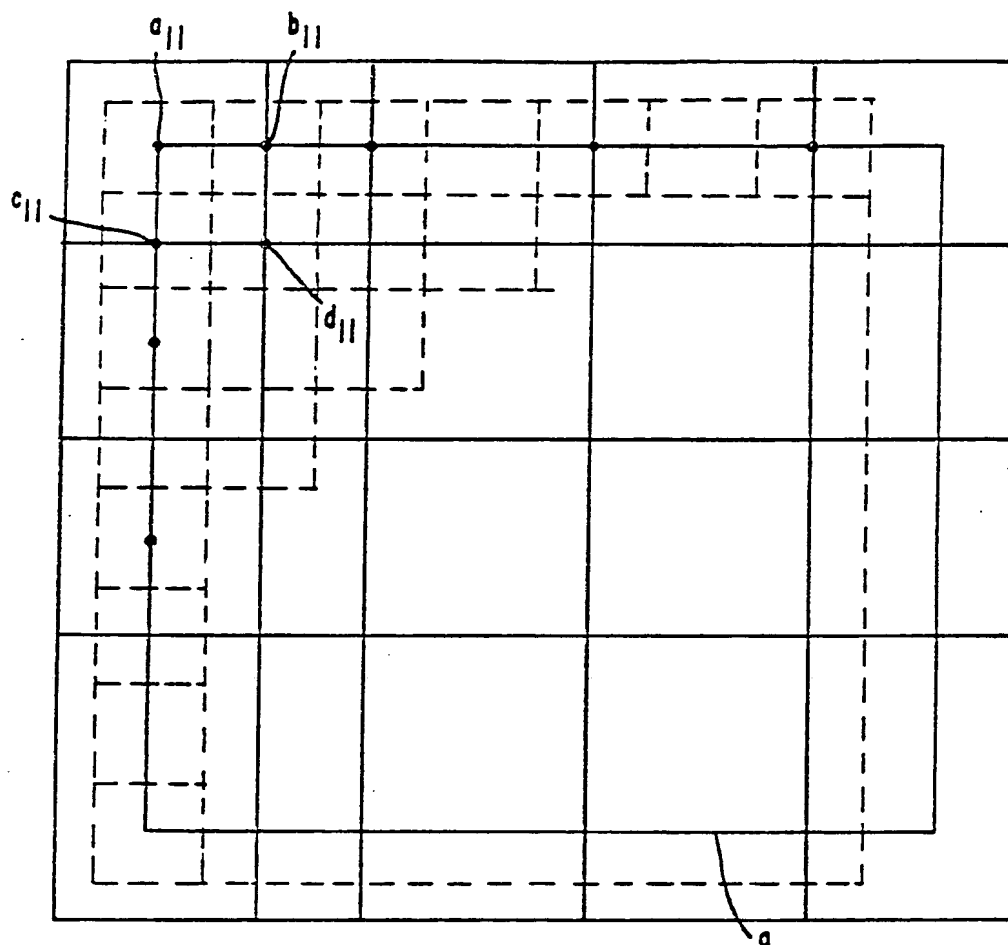


Fig. 2c.

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Fig. 5.

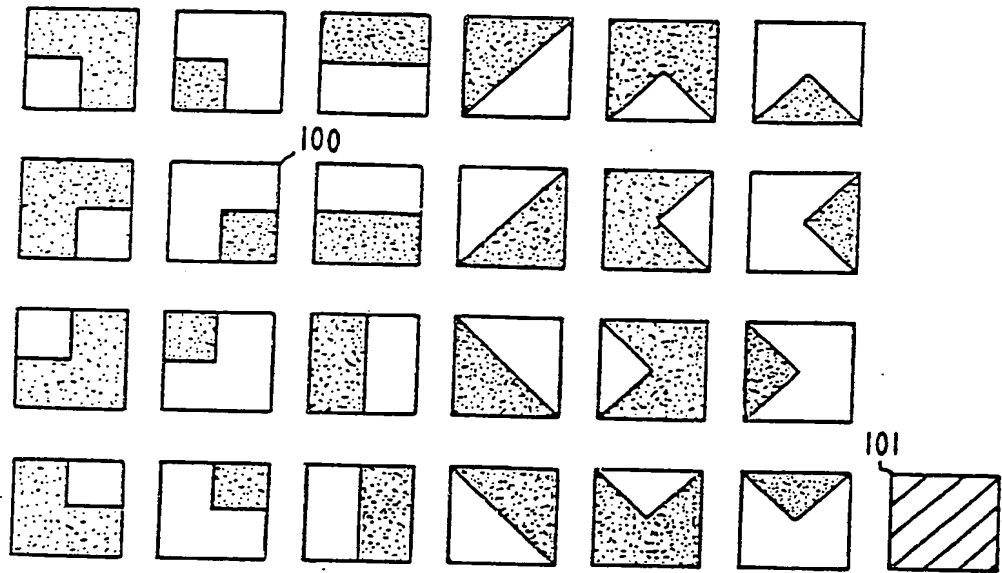
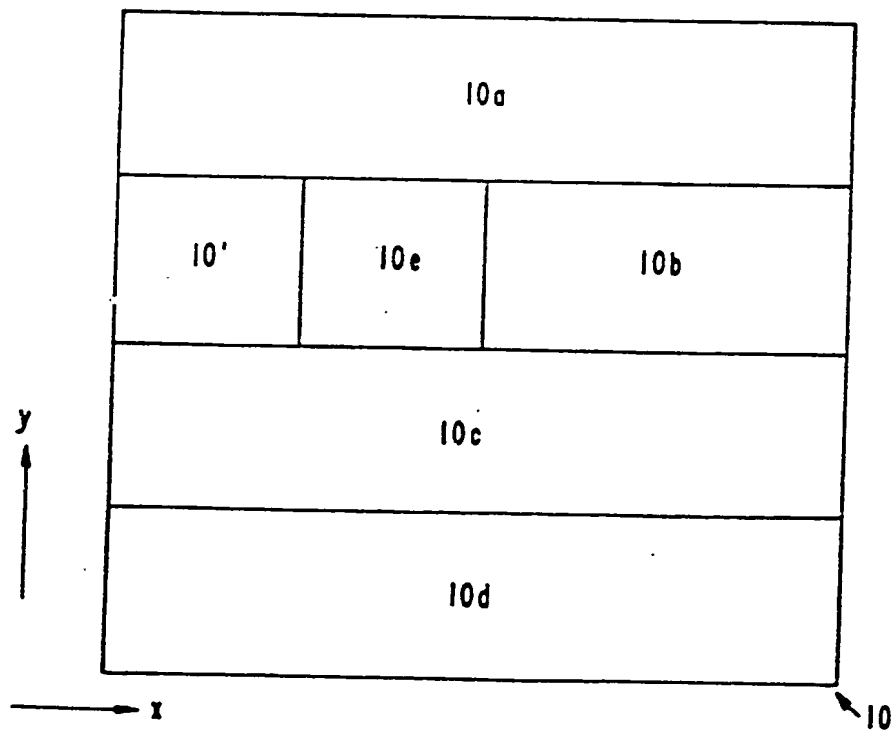
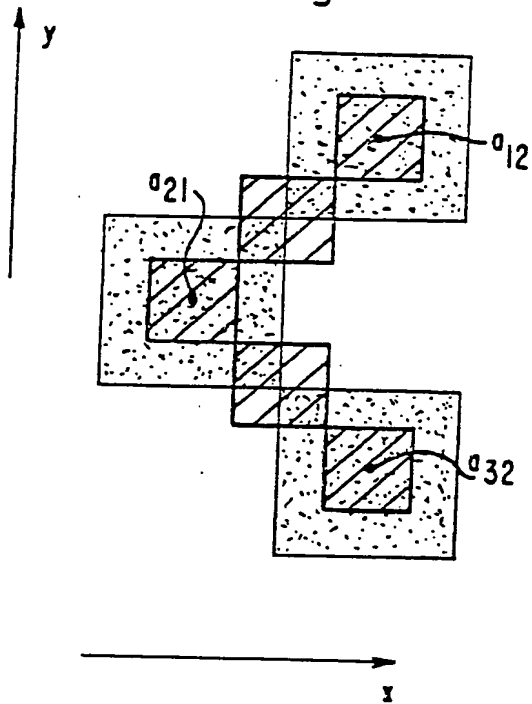


Fig. 3.



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Fig. 4.



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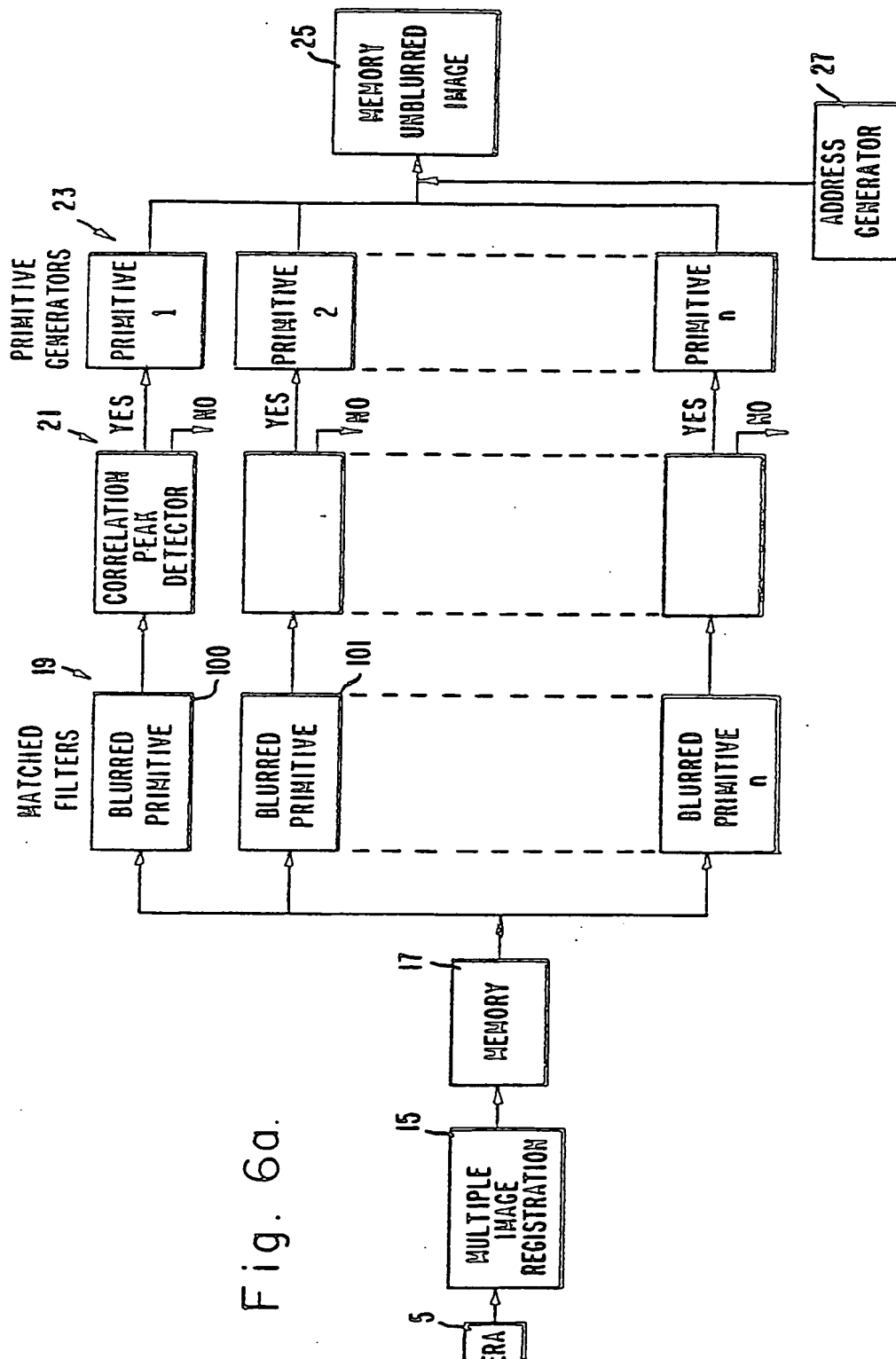
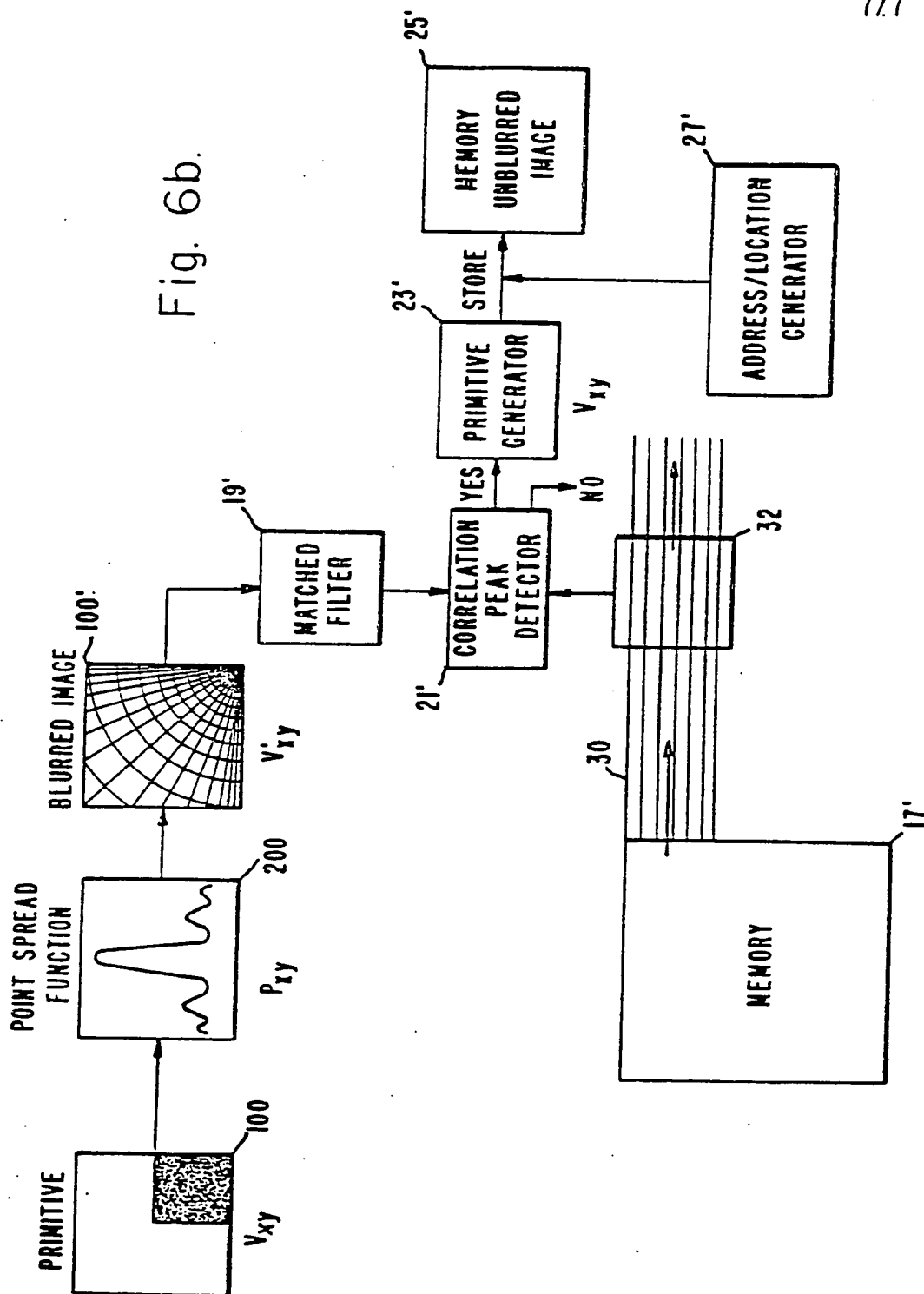


Fig. 6a.

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Fig. 6b.





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(54) Title: RESOLUTION ENHANCEMENT AND ZOOM

(57) Abstract

The resolution is enhanced first by effectively decreasing the scan angle subtended between adjacent samples significantly below that of the Rayleigh limit to obtain an image blurred by the point spread function (or diffraction pattern) of the aperture. The next step is to process this blurred image at least to partially remove the blur. The unblurring process consists of correlating each small segment of the blurred image with blurred images of preconstructed image primitives and then synthesizing a new image comprising a mosaic of spatially correlated original (unblurred) primitives. The blurred images of the primitives are obtained from a complete set of image primitives comprising, ideally, all possible unblurred primitive shapes. These primitives are then blurred by convolution with the point spread function of the aperture of the imager.

